system generally is based on a statistical approach of differentiating amongst relatively larger numbers of cells, and not sorting one cell at a time. Because the arrangement of channels and valves is determined during fabrication of the microfluidic system, each system is designed for a specific operation and typically cannot be used in a different process without modifying its basic structure.

[0013] Integrated circuit (IC) technology is one of the most significant enabling technologies of the last century. IC technology is based on the use of a variety of semiconductor materials (e.g., Silicon Si, Silicon Germanium SiGe, Gallium Arsenide GaAs, Indium Phosphide InP, etc.) to implement a wide variety of electronic components and circuits. Perhaps one of the most prevalent examples of IC technology is CMOS (Complimentary-Metal-Oxide-Semiconductor) technology, with which silicon integrated circuits are fabricated.

[0014] CMOS technology is what made possible advanced computation and communication applications that are now a routine part of everyday life, such as personal computers, cellular telephones, and wireless networks, to name a few. The growth of the computer and communication industry has significantly relied upon continuing advances in the electronic and related arts in connection with reduced size and increased speed of silicon integrated circuits, whose trend is often quantified by Moore's law. Currently, silicon CMOS chips can contain over 100 million transistors and operate at multi-gigahertz (GHz) speeds with structures as small as 90 nanometers. CMOS microfabrication technology has matured significantly over the last decades, making silicon integrated circuits very inexpensive. Despite several advantages, however, neither CMOS nor any other semiconductor-based IC technology has been widely used (i.e., beyond routine data processing functions) to implement structures for biological applications such as sample manipulation and characterization.

SUMMARY

[0015] Applicants have recognized and appreciated that integrated circuit semiconductor-based technology (e.g., Si, SiGe, GaAs, InP, etc.), and especially CMOS technology, provides a viable foundation for the realization of systems and methods for manipulating and characterizing biological materials and other objects of interest. Furthermore, Applicants have recognized and appreciated that by combining CMOS or other semiconductor-based technology with microfluidics, a wide variety of useful and powerful methods and apparatus relating to biological and other materials may be realized.

[0016] In view of the foregoing, various embodiments of the present disclosure are directed to methods and apparatus for one or more of manipulation, detection, imaging, characterization, sorting and assembly of biological or other materials on a micro-scale, involving an integration of CMOS or other semiconductor-based technology and microfluidics.

[0017] For example, one embodiment is directed to an IC/microfluidic hybrid system that combines the power of an integrated circuit chip with the biocompatibility of a microfluidic system. In one aspect of this embodiment, various components relating to the generation of electric and/or magnetic fields of such a hybrid system are implemented on an IC chip that is fabricated using standard protocols (e.g., CMOS) in a chip foundry. In another aspect, the field generating components themselves may be formed using standard CMOS protocols and hence do not require any micromachining techniques (e.g., as in micro-electro-mechanical structures, or MEMS implementations). The electric and/or magnetic fields generated from such an IC chip may be used to manipulate and/or detect one or more dielectric and/or magnetic particles and distinguish different types of particles.

[0018] In particular, in one embodiment, an array of microelectromagnets, or "microcoils," are implemented on an IC chip and configured to produce controllable spatially and/or temporally patterned magnetic fields. In one aspect, the IC chip also may include a programmable digital switching network and one or more current sources configured to independently control the current in each microcoil in the array so as to create the spatially and/or temporally patterned magnetic fields. In another aspect, the IC chip may further include a temperature regulation system to facilitate biocompatibility of the hybrid system.

[0019] In another embodiment, an array of microelectrodes, or "microposts," are implemented on an IC chip and configured to produce controllable spatially and/or temporally patterned electric fields to manipulate particles of interest based on dielectrophoresis principles. In one aspect, the IC chip also may include a programmable digital switching network and one or more voltage sources configured to independently control the voltage across each micropost in the array so as to create the spatially and/or temporally patterned electric fields. As in the previous embodiment, in another aspect, the IC chip may further include a temperature regulation system to facilitate biocompatibility of the hybrid system.

[0020] In yet another embodiment, an array of microcoils implemented on an IC chip may be configured to produce both controllable, spatially and/or temporally patterned, electric fields and/or magnetic fields. In one aspect, the IC chip also may include a programmable digital switching network, together with one or more current sources and one or more voltage sources, configured to independently control the current in and voltage across each microcoil in the array to create the spatially and/or temporally patterned magnetic fields and electric fields. In another aspect of this embodiment, the microcoils effectively act as microposts when a voltage is applied across them, thereby functioning to manipulate particles of interest based on dielectrophoresis principles as in the previous embodiment. Again, the IC chip according to this embodiment may further include a temperature regulation system to facilitate biocompatibility of the hybrid system.

[0021] In connection with any of the foregoing embodiments related to electric and/or magnetic field generation, according to yet another embodiment of the present disclosure, a microfluidic system may be fabricated either directly on top of the IC chip, or as a separate entity that is then appropriately bonded to the IC chip, to facilitate the introduction and removal of cells in a biocompatible environment, or other particles/objects of interest suspended in a fluid. In this manner, the patterned electric and/or magnetic fields generated by the IC chip can trap and move biological cells or other objects inside the microfluidic system.